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ABSTRACT

This paper examines the implications of recent theory and research in cognitive psychology for the understanding and assessment of intelligence. Three major themes are developed. The first has to do with how changes in the social and educational climate for testing can influence the conception of intellectual competence and the technology of testing. The second theme concerns the ways that cognitive psychology, with its emphases on memory, problem-solving, and knowledge acquisition, has begun to provide a new framework for viewing differences in intellectual functioning. Finally, it is argued that study of the kinds of performances required for success in school suggests ways in which intelligence testing can be made more responsive to current social and educational needs. (Author)

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INTELLIGENCE TESTING, COGNITION, AND INSTRUCTION

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This paper examines the implications of recent theory and research in cognitive psychology for the understanding and assessment of intelligence. Three major themes are developed. The first has to do with how changes in the social and educational climate for testing can influence the conception of intellectual competence and the technology of testing. The second theme concerns the ways that cognitive psychology, with its emphases on memory, problem-solving, and knowledge acquisition, has begun to provide a new framework for viewing differences in intellectual functioning. Finally, it is argued that study of the kinds of performances required for success in school suggests ways in which intelligence testing can be made more responsive to current social and educational needs.

The study of intelligence has always occurred within social contexts that have influenced its development to a significant degree. Changing social values have affected the nature of questions asked, and changing social needs have influenced the applications developed and the ensuing public and professional reaction. Indeed, social concern with testing is, in itself, an indication of its success as a social enterprise (Haney 1981). In this respect, the changing climate of opinion, over the past few decades, about the validity and usefulness of intelligence testing is just the most recent part of a long history of social concern. However, there are aspects of the current social response to testing that also make it quite different from those that preceded it. In the past, as society struggled to deal with the range and diversity of individual differences, differential placement based on intelligence testing was part of the

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solution. More recently, however, society has faced a different goal – one of providing this range and diversity with equal opportunities. And for many, testing has now come to represent a part of the problem (e.g., Block and Dworkin 1976; Kamin 1974).

Our goals in this paper are to examine the existing social and educational climate for intelligence testing, and to suggest some directions that future theory and practice in assessment and instruction must take in response to this climate. We approach these goals in the following way. First, we provide an historical overview to the current dissatisfaction with testing, focusing on how emphasis shifted from classification and prediction of intellectual success to development and improvement of intellectual functioning. New, we discuss some recent trends in research on intelligence, focusing on how theories of human cognition have been used to study the nature of intelligence and tests of intellectual ability. Third, we examine the overlap between the knowledge and skills measured by the tests and those required for success in school, focusing on the relationship between vocabulary testing and vocabulary instruction. Finally, we conclude that intellectual assessment and development can become a more integral activity through future theory and research on testing that take into account all three of these influences: (a) the current social context for testing, (b) the framework provided by cognitive theory and research, and (c) the requirements for learning dictated by specific instructional practices.

Social contexts for intelligence testing [1]

In periods when there are few opportunities for the majority, little social concern is focused on individual differences in intellectual competence. Thus, prior to this century, intelligence was conceived, for the most part, as a trait that distinguished mankind from animals rather than as a variable trait of human beings. By the turn of the century, however, quantitative and qualitative differences in intellectual functioning had become topics of scientific interest. Wundt had founded his psychological laboratory, Galton had begun to pursue issues of mental inheritance, and Binet had begun to observe variation in the academic

[1] The issues discussed in this section are examined in more detail in Curtis and Glaser (1981).

success of French school children. Seeking theoretical explanations of these differences as well as social utility, Binet designed the first intelligence test – a method of measured classification that sampled a composite of intellectual abilities and indicated it in terms of mental level.

Like his contemporaries, Binet found it difficult to define what intelligence was, hypothesizing only that levels of mental ability must be distinguishable by qualitative differences in mental processing. Thus, his zeal for measuring something that he did not understand may have reflected his hope that that measurement would bring him closer to that understanding. Regardless of his intentions, however, the existing climate of social values, along with the presence of social needs, made the empirical and quantitative nature of Binet's work attractive. Proceeding in a trial and error fashion, with an atheoretical and pragmatic notion of average level of functioning, Binet designed a test that classified individuals and predicted their scholastic achievement in the existing educational system. Measurement of intelligence no longer had to be viewed as a prerequisite to theoretical investigation – it could be viewed as an end in itself.

As is well known in the history of mental testing in the United States, several events precipitated the enthusiasm with Binet's method of measurement. The first was America's entry into World War I. Requirements for manpower not only created the need to classify and assign large numbers of individuals, but also provided the opportunity to test the effectiveness of group intelligence test administration for these purposes. This functional appeal of tests, with their predictive power, also made them an important part of the increasingly formalized educational activity of the time. With passage of compulsory education laws, the promise that intelligence testing held for dealing with students with divergent skills and from divergent backgrounds ensured their ready acceptance and immediate use in the schools. Finally, with the shift in immigration patterns at the turn of the century, attitudes of nativism, racism, and elitism also led to use of the tests as a means of predicting how quickly individuals would be assimilated into the American way of life.

The effects of this widespread testing activity on the scientific study of intelligence were mixed. On the one hand, testing "broadened and intensified our incentives to research, enlarged public support of our science, and attracted new hosts of workers to our psychological

vineyard" (Terman 1924: 117). But, on the other hand, psychologists were soon to find out that it was much easier to measure individual differences in intelligence than it was to explain them. The technical measurement problem and the practical outcome were much more straightforward. This methodological emphasis, combined with the atheoretical base and widespread testing, led to reification of the intelligence test score. Intelligence came to be viewed as the mental capacity that was indexed by a score on an intelligence test (Boring 1923). As Tuddenham observed, the public as well as professionals readily adopted this new conception of intelligence – one that had "substituted for Binet's idea of intelligence as a shifting complex of interrelated functions, the concept of a single underlying function (faculty) of intelligence" (1962: 490).

Scientific support for a unitary trait conception of intelligence soon followed with Spearman's introduction of "g". His observation that test scores based on a heterogeneous set of items exhibited positive correlations led Spearman to conclude that this commonality among tests was "...a factor which enters into the measurement of ability of all kinds, and which is throughout constant for any individual, although varying greatly for different individuals" (1927: 411). And, as the many incautious conclusions from test scores during the 1920s indicate, this general factor was readily interpreted to be the innate capacity for intellectual development. Cronbach summarizes this period in the history of intelligence testing as follows:

> William James had warned psychology that to understand man was not to write his biography in advance, but the testers came very close, in their estimate as to how much education a man could use and what careers he could thrive in. More serious, when the tests determined who would enter the college preparatory program and before that determined who would go into the 'fast' section of an early grade, the tests began to determine fates. (Cronbach 1975: 11)

The favorable attitude toward use of intelligence tests during the 1920s and 1930s appears to have been a function of both existing scientific knowledge about intellectual abilities and the social context for that knowledge. The conception of intelligence as a measurable, innate, unitary trait not only explained but also provided a panacea for uneven educational progress at all levels of schooling. Since individuals' test scores were assumed to reflect the rate at which their learning took place, use of these test scores for selection and tracking purposes provided a means for continuing to deal with an increasingly larger and diversified school population.

Testing, from this period forward, took a central role in decisions about schooling. The development of factor analytic techniques in the 1930s indicated that, rather than a unitary trait, tests tapped several different abilities. However, attempts to further differentiate how patterns of aptitude were related to success in different school performances were largely unsuccessful. Tests of general intelligence, sampling and averaging as they did across a wide variety of task performances, predicted success in school as well as, or better than, tests designed to measure more specific aptitudes for learning. Thus, in accordance with the tests' predictive validity, the kinds of intellectual performances measured by intelligence tests generally came to be thought of by psychologists as "scholastic aptitude"–that is, the ability to do well in school (e.g., see Anastasi and Foley 1949).

Scientific concern was voiced over the fact that predictive validity was of little value in understanding how scholastic aptitude related to instructional activities in the classroom (Cronbach and Gleser 1957; Glaser and Klaus 1962). Again, however, the search for ways in which aptitude interacted with instructional treatments resulted primarily in a reaffirmation of the significance of the correlation between general intelligence and educational outcomes. (See Cronbach and Snow (1977) for a review of this work.) And as long as the needs for predicting how well individuals were suited for the demands of schooling, employment, or defense continued, understanding why the tests worked was largely an academic question. The go/no-go selective information that the tests provided, along with research that continued to lead to improve test development, validity, and standardization, were adequate responses to social demands. But, once social and educational contexts for testing changed, the concern among psychologists changed into widespread societal concern about testing.

Although the sources of this concern were, and continue to be, multifaceted (e.g., see Glaser and Bond 1981), a central issue for educators, psychologists, and the general public alike was the lack of apparent value that intelligence testing had for adapting instructional procedures to the individual being tested. Beginning in the 1960s, the press for increased educational opportunity resulted in a deemphasis of selective testing and increased emphasis on a broader education for all people. The goal was to be less determinant in advance of who was most likely to succeed, and more determinant in the future in the specific educational opportunities that could be provided so that many

more would succeed. As a result of this change in social climate, conceptions and measures of intelligence developed in the context of former concerns – concerns about the innate potential for learning and the prediction of academic success – were no longer viewed as providing the most useful information or instructional guidance. In an essay entitled "Mr. Binet's Test 70 Years Later", Thorndike described the situation in 1975 as follows:

> Accepting the goal of maximizing the effectiveness of education for *all* children and youth, we must face up to the problem that we have long acknowledged but seldom dealt with effectively – the problem of providing for each individual the educational treatment that will be most effective in developing that person's potential. A good measure of scholastic aptitude is not automatically a good guide to the optimal educational treatment. Binet's test, like others used in education, must be judged in terms of its ability to facilitate constructive adaptations of educational programs for individuals. This is the challenge for the next 70 years. (Thorndike 1975: 7)

As Thorndike pointed out, and as we have tried to emphasize with our historical overview, the shift in social concern not only posed new problems for the design and use of intelligence tests, but once again demonstrated the significant effect that those concerns have had on the study of intelligence. Binet's need to measure, along with a social climate that gave meaning to that measurement, had led to acceptance of an operationally convenient, but scientifically weak, conception of intelligence. Once a change in social concerns caused that conception to no longer be a useful one, recognition of the need for a firmer scientific base became a significant part of the controversy over intelligence testing.

One of the outgrowths of the change in the context for a technology of testing has been a reassessment by psychologists of the extent of knowledge about intellectual abilities, and a search for a new conception of intelligence in which to view that knowledge. However, it must be noted that the need for this reassessment and search was voiced long before popular concern over testing came to a peak in the 1970s. Cronbach had, in 1957, warned psychology about the separation that existed between the study of psychometrically identified abilities on the one hand, and research on the variables of learning and instruction on the other. Again, in 1967, Anastasi noted that increasing specialization had led to "a concentration upon techniques for test construction without sufficient consideration of psychological research for interpretation of test scores" (1967: 305). But it has really only been within the

last decade that psychology has begun to renew efforts toward Binet's initial goal of discovering a relation between the thought processes that contribute to intellectual competence and those that are required for success on school-related tasks.

A significant impetus for this renewed effort has been the framework provided by the concepts, techniques, and research approaches of modern cognitive psychology. Before this period, McNemar had concluded in 1964 that:

> There have been thousands of researches on multitudinous variations from organism to organism, and the results fill books on individual differences... But these studies of individual differences never come to grips with the *process*, or operation by which a given organism achieves an intellectual response. (McNemar 1964: 880)

Cognitive psychology, with its emphases on memory, problem-solving, and knowledge acquisition, has provided a paradigm for analysis of these processes as well as the content of cognition. In the section that follows, we describe some of our own recent work in this area, focusing our discussion on those components of cognition that appear to contribute to variation among individuals and across items on intelligence test performance.

Cognitive approaches to intelligence

Cognitive models of learning emphasize the importance of considering two aspects of intellectual functioning – knowledge and process. In such models, an individual's ability to learn is a function of the knowledge that has been acquired and the ways in which this knowledge is processed. Similarly, individual differences in the ability to learn can be attributed to differences in the content and structure of the knowledge base, and to differences in the way that knowledge is accessed, applied, and modified. It must be noted that this view is in sharp contrast to one in which skilled learners are thought to differ from those who are less-skilled simply because of superior mental ability. Instead, cognitive models view intellectual competence as a much more complex function of the knowledge that has been acquired and the processes that act on that knowledge.

Much of the application of cognitive theory to the study of intelli-

gence has involved analyses of the knowledge and processing requirements of items on intelligence tests. This work is predicated on the assumption that these tests are more than predictors of success in school. They are also tools for research that can be used to identify components of intellectual competence, and which can provide valuable insights about the ways these components are used and modified to facilitate learning. From this research, three interrelated factors appear to underly performance on the tests: (a) memory functioning; (b) problem-solving skills; and (c) declarative knowledge (Pellegrino and Glaser 1982). We discuss each of these factors below, describing the research approaches and recent results that have indicated their involvement in test performance.

Memory functioning

The recent upswing in cognitive investigations of intellectual competence began with, what Pellegrino and Glaser (1979) have termed, a "cognitive correlates" approach. That is, comparisons were made between high and low aptitude individuals' performances on relatively simple information processing tasks of the kind studied in the laboratory. With this approach, both speed in accessing information in long-term memory, and agility in manipulating information in short-term memory, were found to be correlated with scores on scholastic aptitude tests (Hunt 1978; Hunt et al. 1973; Hunt et al. 1975). Because the studies were correlational in nature, however, explanation for the mechanisms underlying the relation between laboratory and aptitude test task performances had to be inferred from other theoretical and empirical work.

In the case of speed of processing, access to long-term memory seems to be most efficient when information is activated automatically – that is, without requiring conscious attention (e.g., Shiffrin and Schneider 1977). Since attention is a resource that is limited, slower access to information in long-term memory could be detrimental to aptitude test performance (and to the criterion performances the test predicts) because of the interference that inefficient access can have on execution of higher level processes.

The nature of the relationship between these variables can be better understood by using what Pellegrino and Glaser (1979) call a "cognitive components" approach. Rather than using basic laboratory tasks, indi-

viduals are tested on their ability to execute processes that are hypothesized to be necessary for solution of aptitude test items. The work of Sternberg (1977) has been the pioneering effort in this form of componential analysis. We have used a variant of this approach to study the influences of speed of access of two different kinds of intelligence test tasks: number analogies (Gitomer et al. 1982), and vocabulary test items (Curtis 1981). In number analogies, speed in accessing number facts has been assessed, while in vocabulary items, the variable of interest has been the speed of word recognition. In agreement with previous findings, low aptitude individuals are significantly slower than the high group in accessing both types of long-term memory information. However, consideration of other requirements of item solution (such as representation and manipulation of information) indicates that speed of access is not necessarily a significant factor in explaining success or failure in item solution.

For example, in number analogies, accuracy in verifying the truth of a noncanonical form of a number fact (e.g., $7:28,\ \times 4$) is a much better predictor of skill in solution than is speed in verifying the canonical form (i.e., $7 \times 4 = 28$). The vocabulary results are similar: availability of knowledge about a word's meaning is far more important in getting an item correct than is automatic recognition of that word's name. Thus, individual differences in speed at which information is accessed in long-term memory appears to be related, but only in a general way, to individual differences in aptitude test performance. It may be that the correlation between aptitude score and simple processing speed stems from a shared emphasis on speed in both the laboratory reaction time tasks and the aptitude tests (Carroll 1981), or that differences in activation speed reflect differences in the way that information is organized in long-term memory.

In addition to accessing information in long-term memory, manipulation of information in short-term memory also seems to be required for completion of cognitive tasks. And, because the size of short-term memory is limited, coping with this limitation is another potential bottleneck in aptitude test performance. Agility in manipulating information in short-term memory seems to be of particular importance in solution of figural (Mulholland et al. 1980) and number analogies (Holzman et al. 1982). In figural analogies, spatial and logical transformations must be applied to the elements of the stem and answer terms in order to construct and complete the rule that governs those terms.

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The elements that comprise the terms are easily perceived plane geometric figures. The basic transformations include removing or adding elements; changing size; rotating, reflecting, and displacing elements; and varying element shading. As the number of elements and transformations required to change one term of the analogy into another increases, the load on short-term memory increases. As a consequence, the amount of attention that must be allocated to avoid loss of information must also increase. Low skill individuals are particularly inefficient at these aspects of processing – as the number of transformations required increases, so do errors in solution.

The load on short-term memory imposed by test item elements also seems to be a pervasive influence on accuracy in number analogies (Holzman et al. 1982). The complexity of an analogical rule, as in figural problems, can be characterized by the number of operations required to transform the first number in a pair into the second. Accuracy of solution declines, in both children and adults, as the number of operations that must be performed and coordinated increases. The influence of rule complexity is greater on children's performance, however, than it is on adults. Apparently, adults have developed either larger short-term memories, or have strategies for dealing more effectively with the space that is available. As a consequence, adults are able to successfully coordinate more rule-related information than are children.

The extent to which older and more skilled individuals may be able to represent information in memory in ways that reduce load on memory and strain on processing resources is a topic for future research. Many memory and problem-solving tasks depend on the use of strategies to facilitate such basic processing activities as manipulating and maintaining information in memory. Research on figural and number analogies indicates the importance of understanding the way that encoding of task content can interact with processing capabilities. Related work on verbal test content is discussed in the section that follows.

Problem-solving skills

Effective solution of many of the kinds of items on aptitude tests depend on an understanding of the goals of the task, and on ability to structure and use a solution strategy that meets those goals. For example, solution of a verbal analogy can be characterized as a series of

steps directed toward satisfaction of the following goals: (a) identification of the relation between two words; (b) establishment of alignment between two sets of relations; and (c) determination that the degree of alignment for two pairs of words is greater than for alternative pairs (e.g., see Sternberg 1977). Much of the work in the cognitive approach to intellectual competence has focused on investigation of individuals' understanding of these goals and the strategies that they use to satisfy them.

Several studies indicate that reasoning skill in both the verbal (e.g., Heller 1979; Gitomer and Curtis 1983) and numerical (Corsale and Gitomer 1979; Gitomer et al. 1982) domains is related to individual differences in the ability to solve analogies in accordance with problem constraints. Whereas low ability solvers often select an answer that they then justify on nonanalogical grounds, high ability solvers, when they cannot detect a rule, prefer to give up rather than choose an answer that they know is wrong. In verbal analogies, low ability solvers' violations tend to involve either (a) attention to only one relation, or (b) failure to consider that the two relations must be aligned. In number analogies, low ability solutions exhibit (a) more analogically inappropriate computations, and (b) failures to infer rules that allow discriminations among alternative matches.

In addition to these skill differences in knowledge of and attention to the constraints of the analogical reasoning task, protocol analyses also indicate that there is variation in the strategies individuals use in developing an understanding of an item's analogical rule. Two general types of such strategies have thus far been identified: conceptually driven and interactive (Heller 1979; Gitomer and Curtis 1983). In a conceptually driven strategy, an individual's initial understanding of the first relation in an analogy drives evaluation of the answer options, and this understanding is used as the basis for discrimination among those answers. In an interactive strategy, on the other hand, the initial relation either is ambiguous or cannot be identified, and as a consequence, must either be modified or derived on the basis of the meaning inferred from the answer options.

An interactive strategy involves an increasingly detailed specification of the analogical rule and/or consideration of alternative possibilities for that rule. As such, it requires more extensive processing than a conceptually driven strategy. Moreover, differences in reasoning skill appear to be related to individuals' capability for engaging in this more

extensive processing. Low ability solvers are, in general, less likely to modify their initial understanding of the relations in an analogy. This means that on items in which the analogical rule can be easily inferred (i.e., a conceptually driven strategy is appropriate), low ability solvers are able to proceed analogically. However, on items in which the correct rule is more difficult to infer (i.e., an interactive strategy is required), low ability solvers exhibit performances that violate task constraints.

Eye movement patterns and number of eye fixations have been used to corroborate and extend conclusions about the relationship between strategy usage and reasoning skill (Gitomer and Curtis 1983). Although protocol studies provide a rich source of information about solution processes, they also require that the steps used in satisfying a problem goal be slowed down so that they are observable. Eye movement studies, on the other hand, allow the use of more "test-like" presentation and procedure, providing a more accurate view of skill differences in realistic on-line processing. Our initial work indicates that skill differences during solution of verbal analogies are most apparent in the way that individuals process easy vs difficult items. High skill individuals tend to modify their item processing as a function of item difficulty – that is, they take many more word fixations and alternate more often between the stem and answer words on items in which it is difficult to infer an analogical rule. The number and pattern of fixations of low skill individuals, on the other hand, do not seem to differ as much between easy and difficult items. As would be expected from their protocol data, low skill individuals are less likely to engage in more extensive processing on more difficult items.

Solution difficulty can be affected by both (a) familiarity of vocabulary, which affects ease in deriving an analogical rule, and (b) number of possible word relations, which affects ease in establishing alignment between the relations. By systematically varying these influences on item difficulty, their effect on eye fixations and solution can be examined. Again, low ability individuals do not seem to modify their item processing as much as high ability individuals. The high group takes many more fixations on items which are difficult because of vocabulary than those which are difficult because of word relationships. The low group, on the other hand, does not seem as sensitive to the different aspects of item difficulty. We discuss these effects of vocabulary knowledge more fully in the section that follows.

Conceptual knowledge

A major aspect of performance on aptitude and intelligence tests also involves availability of necessary conceptual knowledge within the content domain being tested. In examining skill differences in children's knowledge about numbers (Corsale and Gitomer 1979), the degree of "abstractness" in declarative knowledge emerges as an important factor of success in analogical reasoning. Skilled solvers are more likely to sort numbers into mathematically based groupings, with superordinate labels such as primes, multiplicative, and exponential relationships. Less skilled solvers, on the other hand, tend to use groupings based on operational concepts (e.g., number facts); nonmathematical concepts (e.g., idiosyncratic groupings such as a telephone number); and digit-based groupings (e.g., numbers that all contain 3). A similar result is found when children are asked to generate relationships between pairs of numbers.

Degree of abstractness in declarative knowledge also seems to be one of the factors that distinguishes between high and low verbal aptitude adults (Curtis et al. 1983). Comparisons can be made among the definitions that high and low verbal individuals generate for words about which they each have accurate knowledge. Low verbal individuals' definitions more often tend to be tied to specific contexts in which these words occur, whereas high verbal individuals' definitions consider the words apart from a specific context. Although variations in vocabulary test scores are correlated with differences in the precision of word knowledge (context specific as compared with more abstract decontextualized knowledge), items that are the best discriminators between high and low test scorers are not items that measure this difference. Instead, discriminating vocabulary items do not measure this difference, but are designed to test word meanings about which low verbal individuals tend to have very little knowledge.

In contrast to vocabulary tests as currently designed for assessing verbal aptitude, verbal analogy test performance can be related to levels of declarative knowledge. This appears to be true because of the ways declarative knowledge influences strategies for analogical solutions. As we previously discussed, these strategies are related to item difficulty. Conceptually driven solutions are appropriate when the initial relation can be readily specified, applied, tested, and verified. However, in cases of representational failure (i.e., an inability to specify a relationship

between the initial terms in an analogy) or representational variability (i.e., the existence of more than one possible relationship between the initial terms), an interactive solution strategy is required. The deficits in word knowledge of low verbal individuals make it more likely that representational failure or representational variability will cause them difficulties. However, because of these deficits, they are also less able to subsequently derive or modify an initial relation on the basis of the answer options. In other words, the state of low verbals' conceptual knowledge is such that, while it should be necessary for them to process interactively more often than high verbals, it is less likely that they have the available knowledge to be successful in this strategy.

That representation of knowledge affects the successful solution of aptitude test tasks is suggested by much of the work in both the verbal and numerical domains. High ability individuals seem to have more higher order concepts that allow them to limit their hypotheses about an analogical rule to a few plausible relationships. Low ability individuals, in contrast, appear to have lower order, more idiosyncratic knowledge that prevents them from solving analogies in a rule based fashion. They do not possess the highly constrained organizational structure that the high skill individuals seem to, and as a consequence, do not constrain the relationships that they use to ones that are appropriate to the task.

Summary

We have discussed three interrelated factors that appear to account for differences in aptitude and intelligence test performances of high and low skill individuals. The first is memory limitation, reflected indirectly in text scores by simple processing speed, and more directly by agility in manipulating information in short-term memory. The second ability is problem-solving skill, reflected by individuals' attention to problem goals during solution, and by their ability to use different strategies to satisfy these goals. The third concerns the state of individuals' conceptual knowledge base, reflected both in whether or not appropriate knowledge is available, and in the level at which that knowledge is represented.

What are the implications of these factors for understanding and improving the skills of school learning? On the basis of the tests' predictive validity, the interface between cognitive information

processing theory and the study of intelligence has begun with an identification and analysis of skills required for success in learning. In particular, recent research has been concerned with specifying the processes and knowledge that aptitude and intelligence tests are measuring, at a level that allows explanation of individual subject performances and individual item characteristics. This now sets the stage for a new level of analysis, one that focuses on how these processes and knowledge are instrumental in the school-related performances that the aptitude tests predict. In the section that follows, we begin such an analysis by discussing how the influences of vocabulary knowledge come into play in the relation between aptitude test performance and classroom instruction. We have chosen to focus on vocabulary testing and instruction because, in addition to being one of the single best predictors of verbal intelligence (Carroll 1971; Terman 1918), vocabulary is one of the major factors in reading comprehension.

Vocabulary testing and instruction

Analyses of verbal aptitude test items have indicated how the conceptually rich knowledge bases of high aptitude individuals allow them to recognize and select among semantic attributes of words that are relevant to an item's solution. Low verbal individuals, on the other hand, tend to have a more impoverished conceptual knowledge base, in which attributes are represented less abstractly – that is, in terms tied to the situations or contexts in which the information was acquired.

Our hypothesis is that differences in level of representation of word meaning affect the ability to apply and manipulate word knowledge in a way that can facilitate or retard the comprehension and learning of verbal information. Several of the results discussed in the previous section support such a possibility. First, when differences in the extent of conceptual knowledge possible have been minimized (as can be done in restricted knowledge domains like that of number concepts), high skill individuals are still more efficient in accessing that knowledge and in manipulating its form. Second, solution protocols of high skill analogical reasoners indicate that they are likely to persevere at determining a precise relationship among stem and answer words (e.g., cottage : castle :: peasant : king, because the first two words refer to the homes of the second two words), while low skill reasoners tend more

often to use less complex or ambiguous rules (e.g., the first two words are places to live and the second two are people). Finally eye fixations and eye movements indicate that high skill individuals are more likely to modify their solution processes as a function of item difficulty, while low skill individuals tend to process all problems in the same manner, regardless of their difficulty. In the next section of our paper, we attempt to extend these analyses of skill differences – moving away from performance on psychometric tests of aptitude and intelligence toward their influence on performance in school-related tasks.

Vocabulary and comprehension

Apart from correlational evidence, the influences of word knowledge on skill in comprehending and acquiring information are still not very well understood. Certainly whether or not a word's meaning is known can affect comprehension. Texts that contain many words whose meanings are unknown are poorly comprehended (e.g., Freebody and Anderson 1978). Recent research suggests, however, that there are other aspects of word knowledge that may be of equal importance to success in comprehension (and as a consequence, to the ability to learn new information from what is read).

The first of these has to do with the precision and richness of semantic information that is associated with words whose meanings are familiar to the reader. As comprehension of a text proceeds, the reader constructs a representation in memory of the passage content. When knowledge about a word is precise and semantically rich, the various attributes that are required for understanding that word's meaning in a sentence can be easily accessed. Knowledge about the word's meaning matches other content in the memory structure, and comprehension of the sentence that contains the word is an efficient process.

As defined by their performance on verbal aptitude test items, low verbal individuals know the meanings of a fewer number of words. In addition, however, we noted earlier that the knowledge they do have about words' meanings often tends to be tied to specific contexts in which those words can occur. For example, the meaning of the word "hysterical" might be stored in memory as "a fit of laughter". In such cases, the meanings of these words can be considered to be known in the sense that texts that contain them can be understood and remembered (e.g., "She became hysterical when she heard the joke"). How-

ever, contextually tied word knowledge can also decrease comprehension and recall of what is read – particularly when a word's meaning in a text does not match that knowledge (as would be the case in a sentence like "She became hysterical when she heard about the tragedy"). Thus, even when a text contains words whose meanings are known, low verbals can experience difficulties because of the nature of their word knowledge (Curtis et al. 1983).

In addition to knowing fewer words, and having more contextually tied information about the words that they know, low verbals appear to differ from high verbals in yet another aspect related to comprehension: they are less likely to use context in order to derive the meaning of a word (Sternberg et al. 1982). Why this is so remains unclear at the present time. It may be that low verbals use an inefficient strategy for dealing with unknown words (e.g., see Daalen-Kapteijns and Elshout-Mohr 1981), or that they are unaware of the many cues provided by a text and a word itself to that word's meaning (Sternberg et al. 1982). But better understanding of the influences that the semantic knowledge base has on this ability is necessary. As in the case of verbal analogies, the state of low verbals' word knowledge is such that, although it would be necessary for them to use context to get the meanings of unknown words more often than high verbals, it is less likely that their semantic knowledge is rich, precise, or decontextualized enough to aid them in this process. Getting the meaning of an unknown word from context requires that the context itself has been sufficiently understood. Since low verbals often tend to ignore demands for semantic integration when their knowledge of a word's meaning is not consistent with a context (Curtis et al. 1983), lack of integration may also make it difficult to benefit from context when they encounter an unknown word.

Vocabulary instruction

We have described three aspects of the relationship between vocabulary and comprehension. The first has to do with the range or breadth of word knowledge. Since low verbal individuals know the meanings of fewer words than high verbals, their comprehension is more likely to suffer from a lack in their conceptual knowledge base. The second has to do with the richness or precision of word knowledge. Not only do low verbals know fewer words – they also seem to have less useful

knowledge about the words that they know than high verbals do. Their knowledge is often tied to specific contexts in which the words have occurred, and as a result, their comprehension of texts that contain those words can also be less complete. Third, low verbals seem less able than high verbals to use context to get the meaning of an unknown word. Variables such as strategic knowledge, cue utilization, and comprehension of context all appear to be related to this difference.

We would now like to briefly address how these aspects of word knowledge and comprehension are attended to in vocabulary instruction. Range and precision of word knowledge, along with the ability to use this knowledge to derive new knowledge, underly the correlation between aptitude test performance and the criterion performance it predicts (i.e., comprehension). However, it is our belief that inadequate instructional concern with these factors influences the predictive power of current vocabulary tests. Several features of the way that vocabulary is taught support such a conclusion. First, consider the amount of time that is spent in teaching the meanings of unknown words in the classroom. Apparently it is very little (e.g., see Durkin 1979). Concern in the primary grades is with control of the vocabulary used in texts. Since texts that contain many unknown words are difficult to comprehend, avoidance of new vocabulary is assumed to ease the demands already faced by the child learning to read. As new vocabulary becomes introduced into children's texts, however, little change seems to occur in the amount of instructional time devoted to word meaning. Unknown words whose meanings are not learned thus begin to become a source of comprehension difficulties in the intermediate grades.

Consider now the nature of vocabulary instruction that does occur. Two characteristics seem to be of particular importance with regard to the relationship between vocabulary and comprehension. The first characteristic is related to contextual independence of word knowledge. Examination of children's reading programs indicates that when new words are introduced in a text, very few encounters with these words are provided by the programs (Beck et al. 1979). Provision of a small number of contexts in which a new word can occur promotes the type of contextually-tied word knowledge that is correlated with low scores on a vocabulary test. The second characteristic has to do with the use of context to infer the meaning of an unknown word. Introduction of new vocabulary in basal reading programs seems to rely heavily on this technique for vocabulary instruction (Beck et al. 1979), and, as we have

noted, this is an aspect of verbal processing in which low vocabulary scorers are at a disadvantage.

What can we conclude from this brief analysis of the quantitative and qualitative features of vocabulary instruction? It appears to us that the way that vocabulary is taught does not meet the needs of those who require that instruction the most – the low vocabulary test scorers. Little instructional time seems to be spent in introducing and teaching the meaning of new words, thereby limiting the potential influence of instruction on growth in the range or number of words whose meanings are known. Few encounters with new vocabulary tend to occur within the text, thus limiting the number of contexts with which new words are associated. And finally, emphasis on indirect instructional methods such as inferring word meaning from natural contexts further inhibits the learning of these who are unable to benefit from these techniques. Together, these features of vocabulary instruction all support the conclusion that a large part of the predictive power of vocabulary tests stem from the fact that they measure or are related to those aspects of word knowledge *that are necessary for comprehension but which are not taught*.

How can vocabulary instruction and testing be changed to better meet the needs of low verbal individuals? We begin first with instruction, since significant research in this area has already begun. As we have tried to convey, the relationship between vocabulary and comprehension is not a simple or straightforward one. Although many previous attempts to boost vocabulary knowledge have been successful in raising test scores (e.g., Jenkins et al. 1978; Tuinman and Brady 1974), only a few have affected comprehension (e.g., Beck et al. 1982; Draper and Moeller 1971). The lesson from these efforts is twofold. First, increasing scores on a multiple choice vocabulary test does not necessarily improve performance on the criterion task that the test predicts. Knowledge about a word's meaning can be sufficient to answer a test item correctly but may not be generalized enough to aid in comprehension of a text in which that word occurs (Curtis et al. 1983). And second, in order for comprehension to be improved, vocabulary instruction needs to be rich in the variety and kind of instructional techniques used, and extensive in the number of contexts in which the words are presented (e.g., Beck et al. 1982). Rather than requiring individuals to infer and/or recall an association between a word and its synonym, they must be allowed to explore various aspects

of a word's meaning, by identifying how it relates to other known words and by applying it in various contexts.

The design of appropriate diagnostic instruments can also aid significantly in determining the instructional interventions that will develop verbal competence. Past attempts to improve vocabulary testing have been largely influenced by the desire to increase the predictive power of the tests. New attempts, however, must be guided by the type of information that is necessary to improve performances on the criterion task. Vocabulary tests, in their current form, provide a relative indication of the range or breadth of individuals' word knowledge (see Freebody and Anderson 1978). What they fail to make apparent, however, is potentially useful information about: (a) precision of knowledge about known words; (b) strategies for dealing with unknown words; (c) knowledge about cues within a text that can aid in comprehension; and (d) ability to cope with the demands for semantic integration (Curtis and Glaser 1983). Current research indicates that all of these factors may be indirectly reflected in vocabulary test scores – that is, they are correlated with range of word knowledge. But, in accordance with the shift in emphasis from educational prediction to educational prescription, attention must now be directed toward development of assessment techniques that can more directly inform instructional practice.

Conclusions

We began this essay by examining how social values and needs have influenced the development of conceptions of intellectual competence and the technology of testing. Although mental ability testing had its origins in the scientific study of intelligence, demands for testing encouraged a conception of intelligence that was based more on practical application than on scientific knowledge. As the need for particular kinds of applications diminished with changes in social context, so did social and scientific satisfaction with the conception that had developed. In response to these changes in the social attitude toward testing and in psychological theories of learning and instruction, the attempt to develop a better understanding of intellectual competence and its utility was begun. Analyses of aptitude test tasks have yielded information about individual variation in cognitive process and knowledge, and the

ways that this variation is related to test and school performances.

Our own work in this area has led us to examine the continuity among intelligence testing, cognition, and instruction. We have a better understanding of the cognitive requirements of measures of aptitude and intelligence, and the skills required for success on these tests. However, we have also become impressed with the discontinuities that exist between the skills that are tested and the skills that are taught in school. In particular, current research suggests that the predictive power of verbal aptitude tests stems largely from the fact that those tests are sensitive to differences in the content and process that are required by tasks in school, but which are not a primary focus of instruction in school.

Studies of the relationships between components of cognitive competence and requirements for success in school are of particular importance for maximizing intellectual power and educational attainment in society. Educational systems striving to help individuals succeed require information about the kinds of learning skills that can be enhanced through instructional interventions. Those systems also require diagnostic measures that can indicate who is in need of this instruction. Extending our analyses of the knowledge and processing requirements of aptitude and intelligence test items to the way those and other kinds of performances are required in school should help to make both testing and instruction more responsive to the development of human potential.

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Cet article examine les implications de la théorie et de la recherche récentes en psychologie cognitive pour comprendre et diagnostiquer l'intelligence. Trois thèmes majeurs sont développés ici. Le premier concerne l'influence que peuvent avoir les changements dans le climat social et éducatif des tests sur la conception de la compétence intellectuelle et sur la technologie des tests. Le second thème concerne les moyens par lesquels la psychologie cognitive, en mettant l'accent sur la mémoire, la résolution de problèmes et l'acquisition de la connaissance, a commencé à fournir un nouveau cadre de références pour établir les différences dans le fonctionnement intellectuel. Enfin, il est expliqué que l'étude des différentes sortes de performances nécessaires au succès scolaire, suggère des moyens par lesquels tester l'intelligence pourrait se faire d'une manière plus adaptée aux besoins sociaux et éducatifs actuels.